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(54) Piezo-electric rate sensors.

(57) A method of and apparatus for scale factor compensation for piezo-electric rate sensors (8). Means (32) being provided for maintaining the magnitude of vibration at the primary pick-off point (P_p) substantially constant so as to enable one of the variables of a vibrating structure (β) - the piezo-electric change coefficient to be determined and thereby enable the scale factor of the sensor (8) to be determined in order to enable correction of the sensor output to be made by a scale factor control unit (46) in order to ensure that the output therefrom more accurately reflects the true timing rate of the sensor. This enables such sensors to be employed in applications requiring a higher degree of accuracy than they were previously able to provide.

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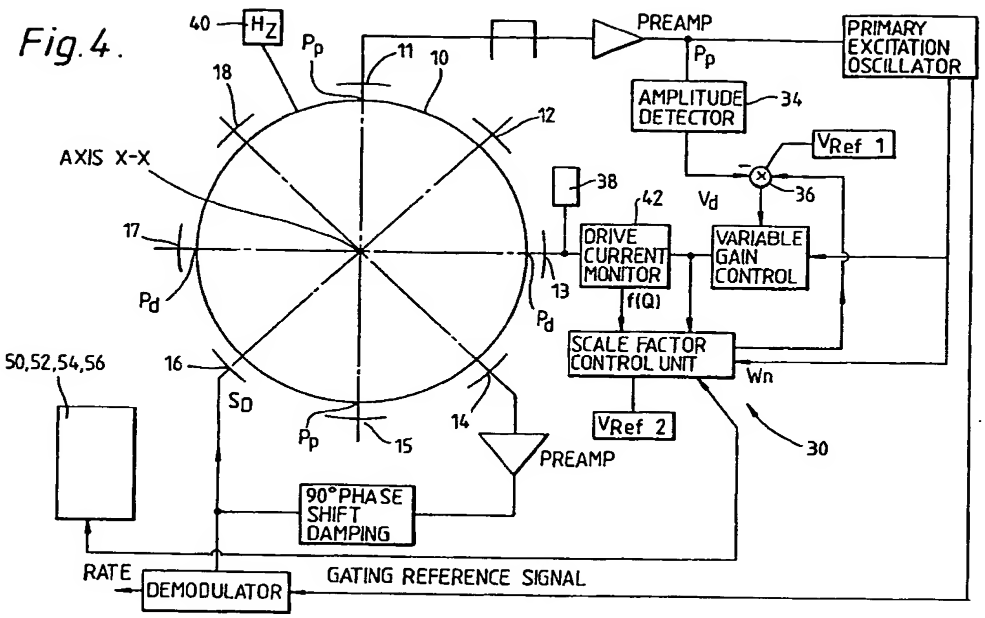
Fig. 4.



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VARIABLE GAIN CONTROL
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50,52,54,56
16
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90° PHASE SHIFT DAMPING
RATE
DEMODULATOR
GATING REFERENCE SIGNAL

The present invention relates to piezo-electric rate sensors and relates particularly, but not exclusively, to a method of and apparatus for scale factor compensation for piezo-electric rate sensors.

There are currently a number of piezo-electric vibrating rate sensors being produced for different applications. Generally, the vibrating portion of the sensor is made from a man made material whose properties vary with both temperature and time. These variations manifest themselves as scale factor variations which results in a difference between the indicated rate and the actual rate and makes them unsuitable for many applications.

One method of avoiding the above mentioned problem is to monitor the temperature and time and modify the scale factor accordingly. Unfortunately, the material properties of the sensors are not exactly reproducible from batch to batch and hence differing variations in the scale factor still present themselves.

There therefore exists a requirement for a method of and apparatus for obtaining the value of those parameters of a piezo-electric rate sensor which vary with both temperature and time so as to enable scale factor compensation to be achieved and hence ensure the accuracy of the sensor.

Accordingly, the present invention provides a method of in process scale factor compensation for a piezo-electric rate sensor comprising the steps of activating a vibration means so as to stimulate the vibration of a vibratable structure at a primary drive point thereon; monitoring the magnitude of vibration at a primary pick-off point on said structure; comparing the magnitude of vibration at the primary pick-off point with a reference value; varying the output of a vibration means so as to vary the magnitude of vibration at the primary drive point in order to maintain the magnitude of vibration at the primary pick-off point substantially constant.

By maintaining the magnitude of vibration at the primary pick-off point substantially constant it is possible to determine the value of the piezo-electric charge co-efficient for the vibrating structure, which varies with temperature, and hence facilitate the determination of the scale factor which must be applied to the sensor readings in order to obtain accurate results therefrom.

Preferably, the magnitude of vibration at the primary pick-off point is monitored by monitoring the signal voltage amplitude in a vibration monitoring means.

Conveniently, the signal voltage amplitude in the vibration monitoring means is compared with the said predetermined value.

Preferably, the output of the vibration means is varied by altering the voltage amplitude of the signal supplied to the vibration means at the primary drive point.

The method includes the further steps of monitoring the drive current in the vibration means and measuring the frequency (W_n) of the vibrating structure.

The additional step of determining the power input at resonance is also taken as is the step of measuring the amplitude of the drive voltage.

In addition to the above the Q factor of the vibrating structure is determined as is the piezo-electric charge coefficient β.

The magnitude of the output for a secondary mode of vibration Sp is measured as is the applied turning rate Ω of the vibrating structure.

Advantageously the scale factor of the sensor is determined from the following equation:

$$\text{Scale factor} = S_p/^{\Omega} = A\ P_d\ \beta_{11},\ \beta_{14}\ (Q/Wn)^2 k$$

Where A and k are constants.

According to a second aspect of the present invention, there is provided a piezo-electric vibrating rate sensor comprising:

a vibrating structure;

vibration means, for vibrating said structure at a primary drive point thereon;

vibration monitoring means, for monitoring the magnitude of vibration at a primary pick-off point on said structure, and

amplitude maintaining means, for maintaining the amplitude of vibration at the primary pick-off point substantially constant.

Preferably, the amplitude maintaining means comprises an amplitude detection means for detecting the amplitude of the vibration at the primary pick-off point, comparator means for comparing the detected amplitude with a reference amplitude value and means for varying the output of the vibration means so as to vary the magnitude of vibration at the primary drive point in order to maintain the magnitude of vibration at the primary pick-off point substantially constant.

Advantageously, the amplitude detection means comprises a voltage measuring means for measuring the voltage in the vibration monitoring means, the reference amplitude value is a voltage value, the comparator comprises a means for comparing the voltage in the vibration monitoring means and the reference voltage and the means for varying the output of the vibration means comprises means for varying the voltage passed to the vibration means.

Conveniently, the means for varying the signal voltage amplitude passed to the vibration means comprises a gain control device.

The sensor may also include drive current monitoring means and frequency measuring means for monitoring the drive current and measuring the frequency of vibration of the structure (W_n).

Advantageously, the sensor includes power input determining means for determining the power input at resonance.

Conveniently, the sensor may include drive voltage measuring means for measuring the magnitude of the drive voltage.

Means may be provided for determining the Q factor of the vibrating structure.

In addition to the above, piezo-electric charge co-efficient determining means may be provided for determining the piezo-electric charge co-efficient β of the vibrating structure.

Advantageously, secondary mode vibration output measuring means are provided for measuring the magnitude of a secondary mode of vibration S_p.

Applied turning rate measuring means may also be provided for measuring the applied turning rate Ω of the vibrating structure.

Preferably, scale factor determining means are provided for determining the scale factor of the sensor so as to ensure accurate determination of a true turning rate.

The present invention will now be more particularly described by way of example only with reference to the accompanying drawings in which,

Figure 1 is a diagrammatic representation of the primary mode vibration pattern in a piezo-electric rate sensor,

Figure 2, is a diagrammatic representation of the secondary mode vibration pattern in a piezo-electric rate sensor.

Figure 3, is a schematic representation of a thin shell vibrating rate sensor in its steady state and operating at a carrier frequency of Wn where Wn is the natural resonant frequency of the sensor resonator, and

Figure 4 is a schematic representation of a piezo-electric rate sensor incorporating a method of and apparatus for scale factor compensation according to the present invention.

Referring to figures 1, 2 and 3, a steady-state thin shell vibrating rate sensor detects sensor turning rates in a manner well known to those skilled in the art and therefore not described in detail herein. However, in brief, the sensor is operated by stimulating a primary mode of vibration (Figure 1) and detecting a turning rate by monitoring the magnitude of the secondary mode vibration pattern (Figure 2). Figure 3 illustrates the steady-state primary and secondary mode signals at a vibrating carrier frequency Wn of the sensor. P_d and P_p represents the input and output for the primary mode whereas S_d and S_p represent the input and output for the secondary mode where turning rate is detected. β is the piezo-electric charge co-efficient concerned with mechanical transducing to the resonator, Q is the resonator Q-factor of resonance around the operational frequency W_n. Ω is the applied turning rate, k is a constant associated with the form of the resonator and variable q_p is the primary mode vibration velocity which is linked by the rate related coriolis force to the secondary mode.

Referring to Figure 4, a primary mode of vibration is set up in a vibrating structure 10 by energising force electrodes 13 and 17 respectively to establish a double elliptical vibration pattern as shown at A in Figure 1. The magnitude of the primary mode of vibration is detected by detecting electrodes 11 and 15 positioned orthogonal to electrodes 13 and 17. When the sensor is rotated about axis x-x the direction of the vibrating mode lags behind the vibrating structure 10 and this lagging behind corresponds to the excitation of a secondary mode of vibration having a double elliptical vibration pattern as shown at B in Figure 2. The amplitude of the second mode is measured by using appropriate pairs of detector electrodes 12 and 16 and 14 and 18 respectively. The amplitude of this signal, when demodulated with respect to the oscillator output, is used as a measure of the rotation rate that is applied to the sensor.

Variations in the properties of the vibrating structure which vary with both temperature and time manifest themselves as scale factor variations which mean that a difference will exist between the indicated rate, as determined by demodulating the output signal from the secondary mode of vibration, and the actual rate. These variations mean that such sensors are unsuitable for many applications in which high degrees of accuracy are required. The present invention attempts to solve the problem by providing a method of and apparatus for scale factor compensation such that the accuracy of piezo-electric rate sensors and the like can be improved thereby to enable such sensors to be used in applications they were previously considered unsuitable for. The properties of the vibrating structure which vary with time and/or temperature are β - the piezo-electric charge coefficient concerned with mechanical transducing to the resonator, Q the resonator Q factor of resonance around the operational frequency and Wn the natural resonant frequency of the vibrating structure. As the scale factor value is dependent upon the value of each and every one of these variables it is normally impossible to accurately determine the scale factor value and hence impossible to accurately compensate for the variations in the demodulated output caused by said variables.

In the present invention, there is provided a method of and apparatus for scale factor compensation for a piezo-electric rate sensor. The apparatus comprises scale factor compensation means shown generally at 30 in Figure 4.

In detail the means 30 comprises vibration means in the form of excitation electrodes 13, 17 for vibrating a vibrating structure 10 at a primary drive point P_d thereon, vibration monitoring means in the form of detector electrodes 11, 15 for monitoring the magnitude of vibration at a primary pick-off point P_p thereon and amplitude maintaining means shown generally at 32 for maintaining the amplitude of vibration at the primary pick-off point substantially constant. The amplitude maintaining means 32 comprises an amplitude detection means in the form of a voltage detection means 34 for measuring the voltage in the vibration monitoring means 11, 15, comparator means 36 for comparing the detected voltage value with a reference amplitude value in the form of voltage V ref 1, and a gain control device 37 for varying the signal voltage amplitude passed to the vibration means 13, 17 in accordance with a difference signal V_d passed from the comparator means 36 so as to maintain the magnitude of vibration at the primary pick-off point P_p constant.

By maintaining the magnitude of vibration at the primary pick-off point P_p constant it is possible to determine the value of one of the variables, namely, the piezo-electric charge co-efficient β of the vibrating structure from the following equation:

$$P_d = (K_d \, Vref1 \, W_n)/(A \, \beta_{12} \, \beta_{11} \, Q) \qquad (1)$$

in which P_d is the drive voltage amplitude which may be monitored by drive voltage measuring means 38; K_d is a constant Vref1 is the value of the reference voltage; Wn is the frequency of vibration of the vibrating structure and can be monitored by frequency measuring means 40; A is a second constant; β_{12} is the piezo-electric charge co-efficient of the vibrating structure at electrode 12 which for a uniform vibrating structure is substantially equal to that at electrode 11, and Q is the Q factor of the vibrating structure which is equal to the energy loss from the vibrating structure 10 and hence can be calculated from Pd x id where id = the drive current which can be monitored by drive current monitor 42. It should be noted that by adopting this approach, the Q factor can be determined whilst the sensor is in operation without interrupting the sensor operation. A method of in process monitoring of the Q factor is therefore provided. The Q factor is in fact known to vary considerably with temperature for a number of sintered man-made piezo-electric materials and hence adoption of this process will significantly increase the accuracy of scale factor determination which is outlined below.

It will be appreciated that in this configuration, the primary pick-off amplitude P_p is stabilised to constant amplitude such that

$$P_p = kd \, Vref\,1 \qquad (2)$$

and

$$q_p = (kd \, Vref\,1)/(A \, \beta) \qquad (3)$$

Where q_p = the magnitude of the movement which gives rise to the coriolis effect in the sensor.

By modifying the primary pick-off level the overall scale factor is also desensitised to changes in the β and Wn. This approach is applicable to both open and closed loop vibrating structure rate sensors.

The scale factor SF of the vibrating rate sensor may be determined from the following equation:

$$SF = S_p/\Omega = A \, P_d \, \beta_{11} \, \beta_{14} \, (Q/Wn)^2 k.$$

Where Sp = the magnitude of the secondary mode of vibration and can be determined by monitoring the voltage at output electrode 18 with a secondary mode vibration output measuring means 44; Ω is the applied turning rate and may be measured by an applied turning rate measuring means shown schematically at 46 β_{11} β_{14} is substantially equal to β_{12} β_{11} determined above.

Determination of the scale factor by this method enables correction of the sensor output to be made by the scale factor control unit 46 in order to ensure that the output therefrom more accurately reflects the true turning rate of the sensor, thereby enabling such sensors to be employed in applications requiring a higher degree of accuracy than they were previously able to provide.

Separate means shown schematically at 50 to 56 for determining the power input a resonance 50; the Q factor 52 of the vibrating structure; the piezo-electric charge co-efficient β54; and the applied turning rate 56.

Claims

1. A method of in process scale factor compensation for a piezo-electric rate sensor characterised by the steps of activating a vibration means (13, 17) so as to stimulate the vibration of a vibratable structure (10) at a primary drive point (P_d) thereon; monitoring the magnitude of vibration at a primary pick-off point (P_p) on said structure (10); comparing the magnitude of vibration at the primary pick-off point (P_p) with a reference value (Vref1); varying the output of a vibration means (13, 17) so as to vary the magnitude of vibration at the primary drive point (P_d) in order to maintain the magnitude of vibration at the primary pick-off point (P_p) substantially constant.

2. A method as claimed in claim 1 in which the magnitude of vibration at the primary pick-off point (P_p) is monitored by monitoring the signal voltage amplitude in a vibration monitoring means (11, 15).

3. A method as claimed in claim 2 in which the signal voltage amplitude in the vibration monitoring means (11, 15) is compared with the said predetermined value (Vref1).

4. A method as claimed in claim 3 in which the output of the vibration means (13, 17) is varied by altering the voltage amplitude of the signal supplied to the vibration means (13, 17) at the primary drive point (P_p).

5. A method as claimed in any one of claims 1 to 4 including the steps of monitoring the drive current (id) in the vibration means (13, 17) and measuring the frequency (Wn) of the vibrating structure (10).

6. A method as claimed in claim 5 including the step of the determining the power input at resonance.

7. A method claimed in claim 5 or claim 6 including the step of measuring the amplitude of the drive voltage.

8. A method claimed in claim 7 including the step of determining the Q factor of the vibrating structure.

9. A method as claimed in claim 8 including the step of determining the piezo-electric charge coefficient (β) of the vibrating structure.

10. A method as claimed in claim 9 including the step of measuring the magnitude of the output for a secondary mode of vibration (Sp).

11. A method as claimed in claim 10 including the step of measuring the applied turning rate of the vibrating structure (Ω).

12. A method as claimed in claim 11 including the step of determining the scale factor (SF) of the sensor from the following equation:

$$\text{Scale factor} = Sp/\Omega = A\,P_d\,\beta_{11}\,\beta_{14}\,(Q/Wn)^2 k$$

Where A and k are constants.

13. A piezo-electric vibrating rate sensor comprising:

a vibrating structure (10);

vibration means (13, 17), for vibrating said structure at a primary drive point (P_d) thereon;

vibration monitoring means (11, 15), for monitoring the magnitude of vibration at a primary pick-off point (P_p) on said structure, characterised by the provision of

amplitude maintaining means (30), for maintaining the amplitude of vibration at the primary pick-off point (P_p) substantially constant.

14. A piezo-electric vibrating rate sensor as claimed in claim 13 in which the amplitude maintaining means (30) comprises an amplitude detection means (34) for detecting the amplitude of the vibration at the primary pick-off point (P_p), comparator means (36) for comparing the detected amplitude with a reference amplitude value (Vref1) and means (37) for varying the output of the vibration means (13, 17) so as to vary the magnitude of vibration at the primary drive point (P_d) in order to maintain the magnitude of vibration at the primary pick-off point (P_p) substantially constant.

15. A piezo-electric vibrating rate sensor as claimed in claim 14 in which the amplitude detection means (37) comprises a voltage measuring means for measuring the voltage in the vibration monitoring means (11, 15), the reference amplitude value (Vref1) is a voltage value, the comparator (36) comprises a means for comparing the voltage in the vibration monitoring means (11, 15) and the reference voltage (Vref1) and the means (37) for varying the output of the vibration means comprises means for varying the signal voltage amplitude passed to the vibration means.

16. A piezo-electric vibrating rate sensor as claimed in claim 15 in which the means (37) for varying the signal voltage amplitude passed to the vibration means (13, 17) comprises a gain control device (37).

17. A piezo-electric vibration rate sensor as claimed in claim 15 or claim 16 including drive current monitoring means (42) and frequency measuring means (40) for monitoring the drive current (id) and measuring the frequency of vibration of the structure (Wn) respectively.

18. A piezo-electric vibration rate sensor as claimed in any one of claims 15 to 17 including power input determining means (50) for determining the power input at resonance.

19. A piezo-electric vibration rate sensor as

claimed in any one of claims 15 to 18 including drive voltage measuring means (38) for measuring the magnitude of the drive voltage.

20. A piezo-electric vibration rate sensor as claimed in any one of claims 15 to 19 including Q factor determining means (52) for determining the Q factor of the vibrating structure (10).

21. A piezo-electric vibration rate sensor as claimed in any one of claims 15 to 20 including piezo-electric charge co-efficient determining means (54) for determining the piezo-electric charge co-efficient (β) of the vibrating structure (10).

22. A piezo-electric vibration rate sensor as claimed in any one of claims 15 to 21 including secondary mode vibration output measuring means (44) for measuring the magnitude of a secondary mode of vibration (Sp).

23. A piezo-electric vibration rate sensor as claimed in any of of claims 15 to 22 including applied turning rate measuring means (56) for measuring the applied turning rate (Ω) of the vibrating structure (10).

24. A piezo-electric vibration rate sensor as claimed in any one of claims 15 to 23 including scale factor determining means (46) for determining the scale factor (SF) of the sensor so as to ensure accurate determination of a true turning rate.

Fig.1.

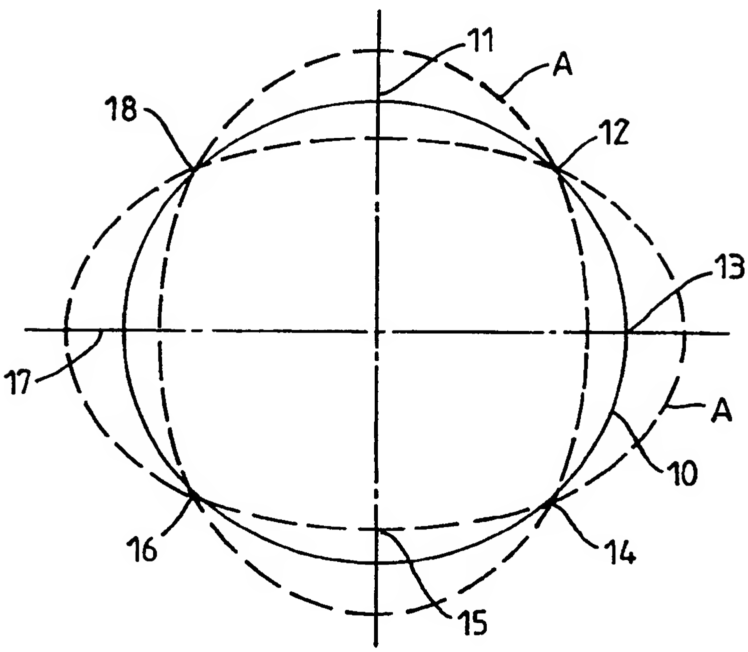


Fig. 2.

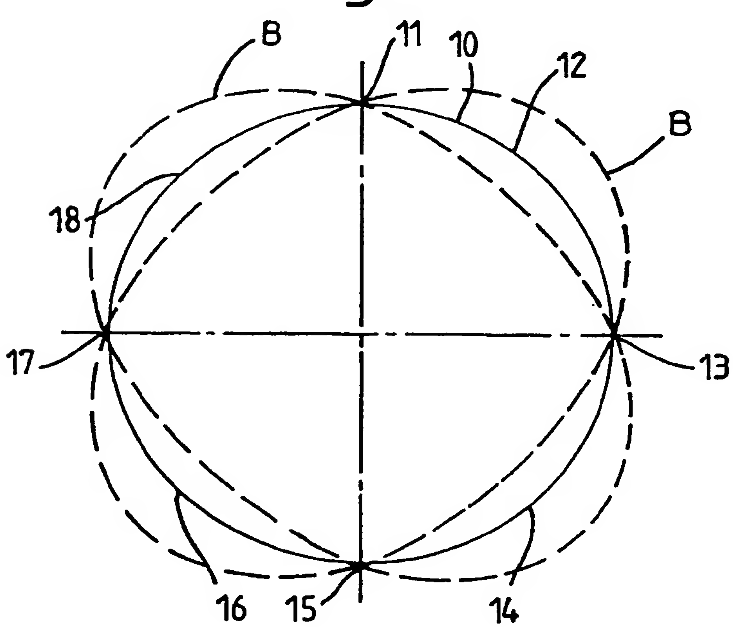
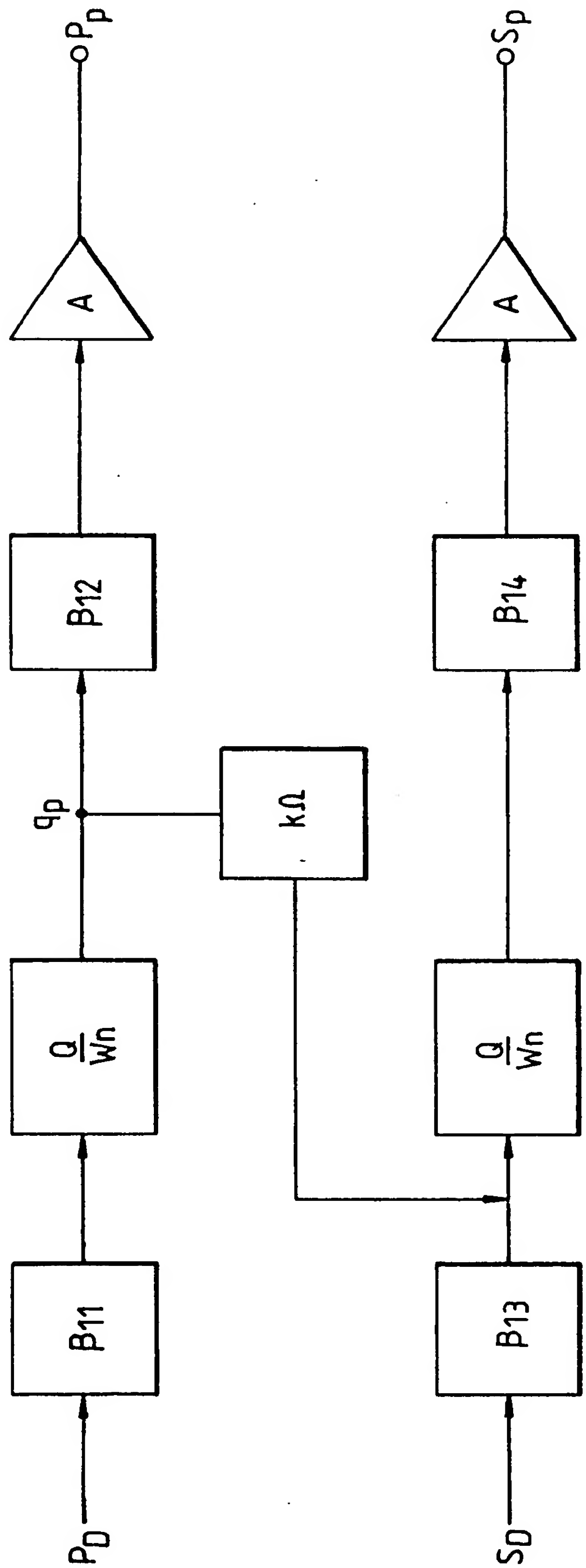
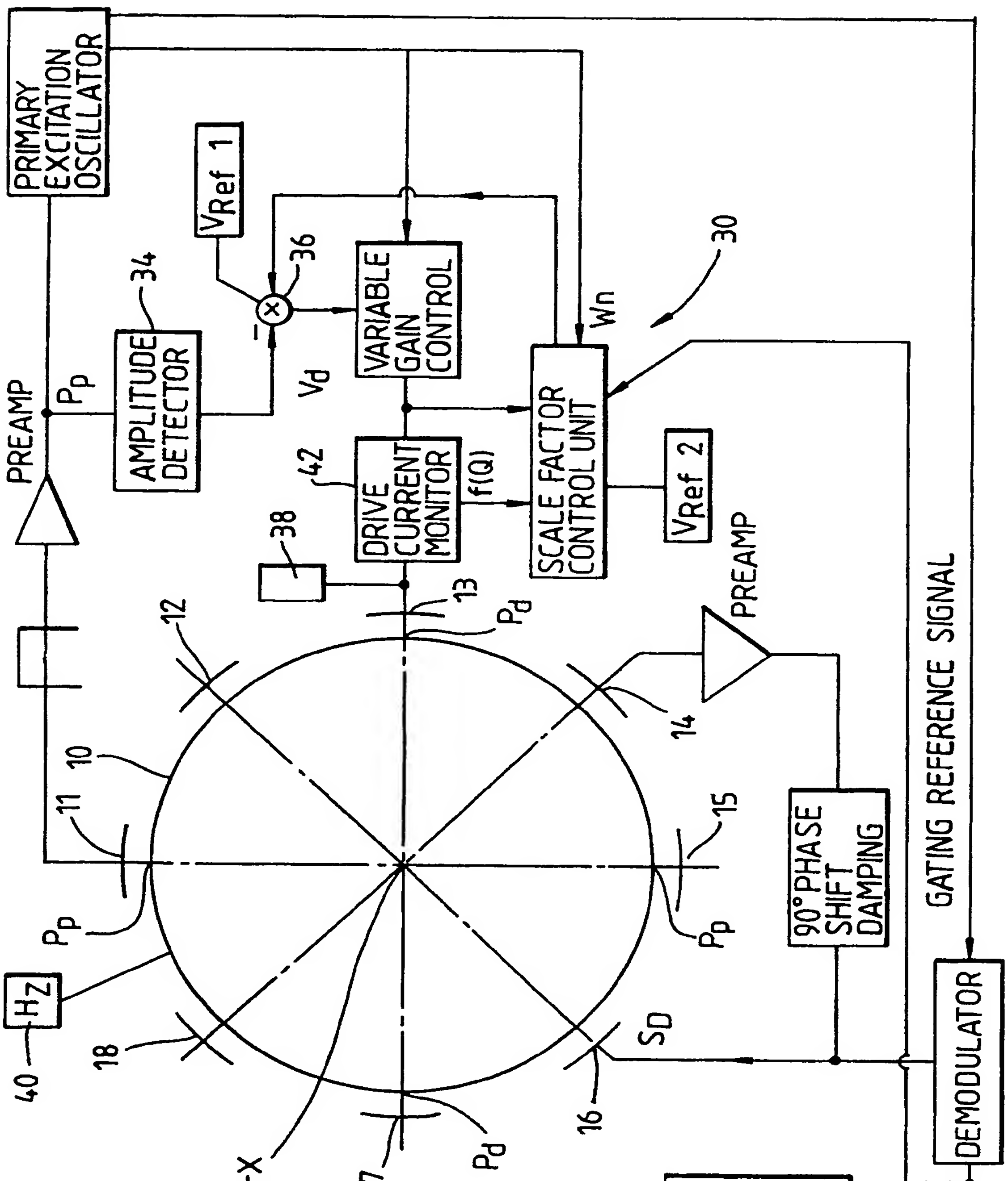


Fig. 3.

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50,52,54,56

Fig.4.

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(54) Piezo-electric rate sensors.

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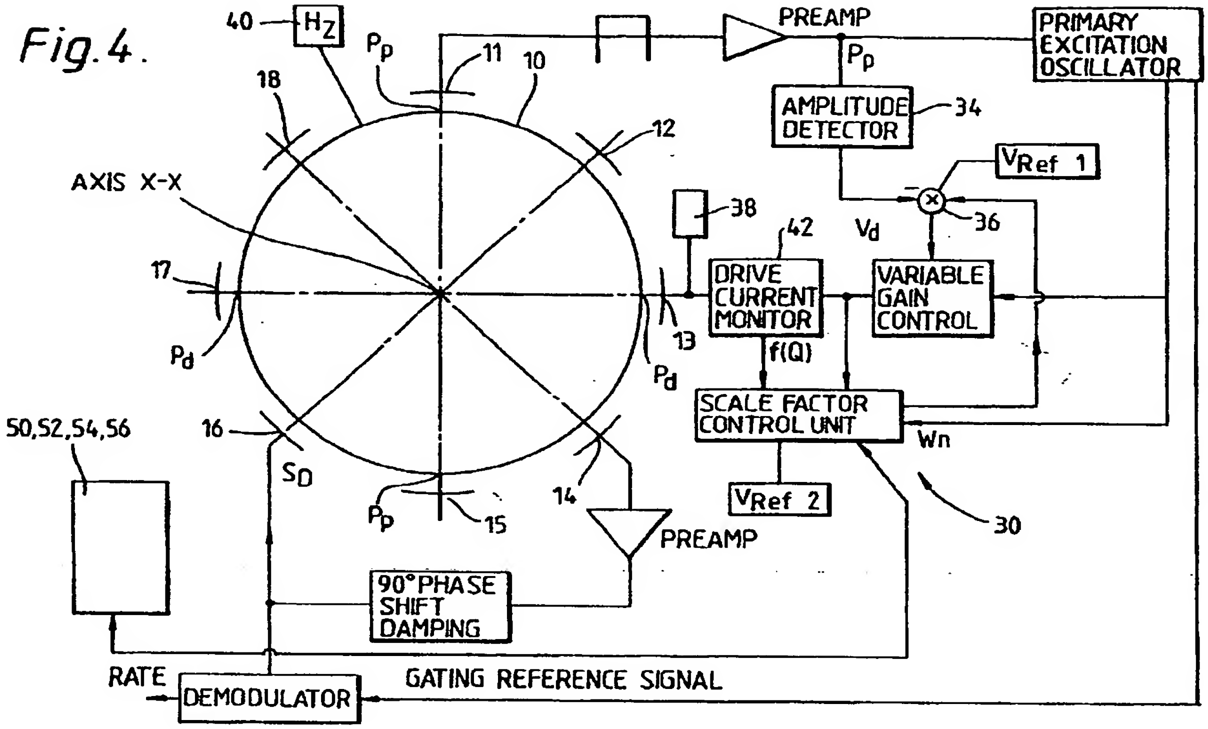
Fig. 4.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EUROPEAN SEARCH REPORT

Application Number

EP 91 20 3396

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
P,X	EP-A-0 411 849 (BRITISH AEROSPACE) * column 3, line 26 - column 4, line 9 * * figure 4 * ---	1,11,13, 23	G01P9/04 G01C19/56 G01P3/44
A	GB-A-2 061 502 (MARCONI) * page 2, line 53 - line 75; figures 2,3 * ---	1,11,13, 23	
A	IEEE POSITION LOCATION AND NAVIGATION SYMPOSIUM, Las Vegas 20-23 March, 1990 HARRIS:"START,a broad application spectrum gyro for the 1990's" , p21-28, XP163761 * page 23, right column, line 1 - page 24, left column, line 25; figure 2 * ---	1,11,13, 23	
A	EP-A-0 153 189 (NATIONAL RESEARCH) * page 6, line 27 - page 7, line 24 * * figure 6 * -----	1,11,13, 23	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			G01P G01C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 JANUARY 1993	JONSSON P.O.

CATEGORY OF CITED DOCUMENTS

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